Transformation of Polarization Type and Triple Splitting During Propagation of Signals in the Ionosphere

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TRANSFORMATION OF POLARIZATION TYPE AND TRIPLE SPLITTING DURING ~~THE~~ PROPAGATION OF ~~THE~~ SIGNALS IN THE IONOSPHERE

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As we know, the ionosphere is a non-homogeneous anisotropic medium. Because of the anisotropy of the ionosphere, the electromagnetic wave which is propagated in it splits into two waves -- "common" and "uncommon", differing in phase speed and polarization type.

The refraction exponent and the polarization of the "common" and "uncommon" waves are related to the angle between the propagation direction and the direction of the tension vector of the earth magnetic field H_0. They are also related to the quantity $u = \frac{4\pi Ne^2}{m\omega^2}$ which is the function of the electronic concentration (thickness) of the layer and of the wave frequency, where N(z) is the electronic concentration of the layer; e and m are the charge and the mass of the electron; and ω is the wave frequency.

In accordance with the theory of the magnetic-ionic effect, the exponent of refraction in the ionosphere is

$$n_{1,2}^2 = 1 - \frac{2u(1-u)}{2(1-u) - w^2 s_0^2 \pm \sqrt{u^4 s_0^4 + 4w^2 c_0^2 (1-u)^2}}$$

and the polarization factor is

$$P_{1,2} = \frac{E_x}{E_y} = \frac{(1-u)i}{\frac{ws_0^2}{2c_0} \mp \sqrt{\left(\frac{ws_0^2}{2c_0}\right)^2 + (1-u)^2}}$$

The upper symbol of the root corresponds to the "common" wave, the lower symbol, to the "uncommon" wave: $c_o = \cos\theta$, $s_o = \sin\theta$ (θ is the angle between the propagation direction and the tension vector of the earth magnetic field); $\psi = \frac{\Omega}{\omega}$, $\Omega = \frac{eH_o}{mc}$. The curves showing the relation between n^2, P and u, θ are shown in Figures 1 and 2.

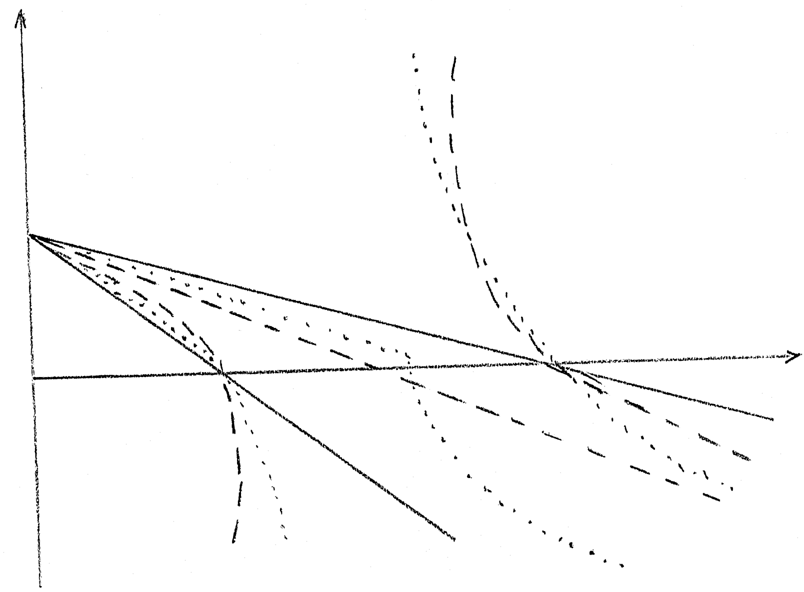

Figure I

Relation between the square of the ionosphere refraction exponent and the quentity $u = \frac{4\pi e^2}{m\omega^2}$. (1) With longitudinal propagation ($\theta = 0^o$). (2) With transversal propagation ($\theta = 90^o$). (3) With propagation at an angle of 45 degrees to

H_o ($\theta = 45^o$).

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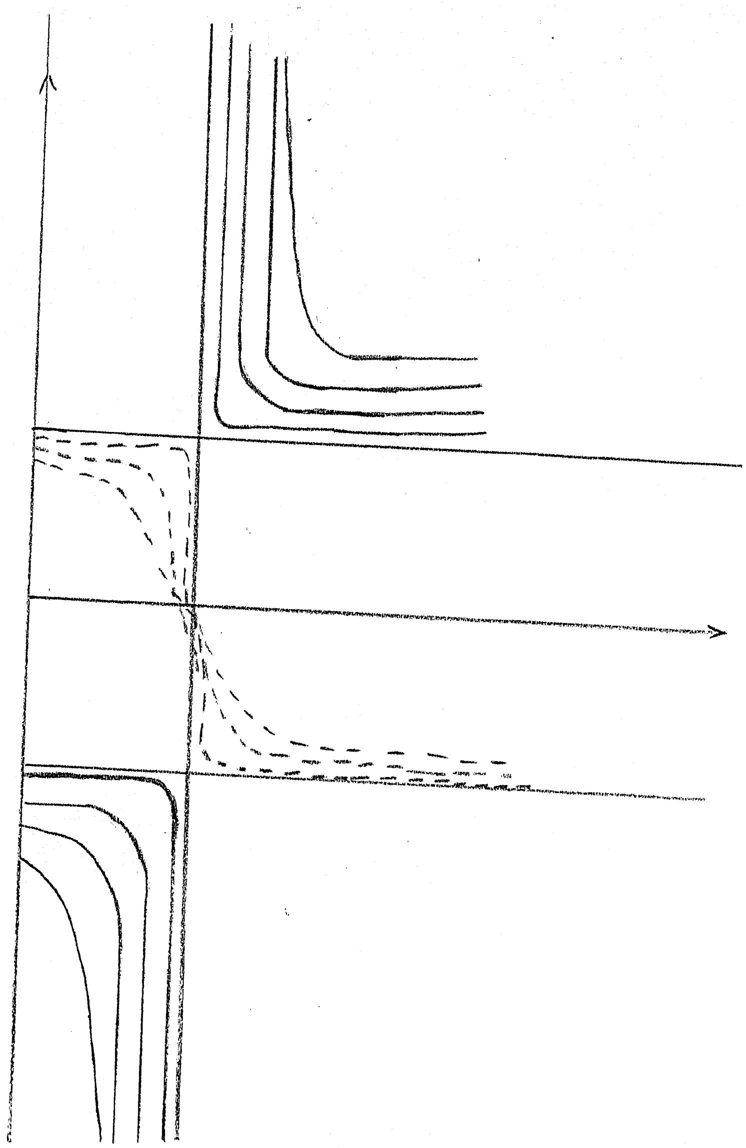

Figure 2

Relationship between the polarization factor and the quantity u with different values of θ. The continuous lines indicate the common wave polarization factor (P_1); the dotted lines indicate the uncommon wave polarization factor (P_2).

Both waves are linearly polarized when the propagation occurs perpendicularly to the tension vector of the earth magnetic field (transversal propagation) (θ = 90 degrees). The oscillations of the electric vector in the common wave take place parallel to the X axis, while in the uncommon wave they occur parallel to the Y axis. The polarization factor is not related to the electron concentration.

With a propagation parallel to the vector H_o (longitudinal propagation) ($\theta = 0^o$), both waves are polarized along a circle. The common wave has a left polarization, while the uncommon wave has a right polarization. The polarization factor is not related to the electron concentration.

With a propagation under an acute angle to the tension vector of the earth magnetic field both waves are polarized elliptically. The polarization factor is a function of the electron concentration. When $u < 1$, the common wave has a left polarization, and the uncommon one has a right polarization. When $u = 1$, both waves are polarized in a linear fashion. The electric vector of the common wave is parallel to the X axis, while the electric vector of the uncommon wave is parallel to the Y axis. When $u > 1$, both waves again have an elliptical polarization, but the rotation direction of the polarization plane changes: now the common wave has a right and the uncommon wave a left polarization. As we may see from the formula and the graph set up for the refraction exponent, the common wave refraction exponent becomes equal to zero when $u = 1$, while the uncommon wave refraction exponent becomes equal to zero with two values of u: $u = 1 - w$, and $u = 1 + w$ with all values of Θ, except $\Theta = 0^o$. When $\Theta = 0^o$, the refraction exponent becomes equal to zero only at two points: $u = 1 - w$ and $u = 1 + w$.

The question of the possibility of the appearance of three components during the reflection of the radio impulse from the ionosphere, respectiveto the three values of u with which the refraction exponent becomes equal to zero, is debatable.

A number of authors [2] affirm that the reflection corresponding to the value $u = 1 + w$ may not happen because the wave in the region with the given electron concentration is always split into only two components: the uncommon wave is fully reflected at the level corresponding to the lowest electron concentration $u = 1 - w$, while only the common wave can penetrate higher. According to the opinion of the cited authors this component is fully reflected with $u = 1$.

Other authors, like M. Taylor [4], Fersterling and Lassen [4](in work carried out in 1933), indicate the possibility of reflection corresponding to the third value of $u = 1 + w$. In work carried out in 1943 under the direction of Fersterling, Krautkramer denies the possibility of a triple splitting. According to the observations of Soviet ionosphere stations [5, 6] during winter months and night hours, the height-- frequency characteristics are often composed not of two components, but of four, and sometimes even of a larger number of components.

One of the possible explanations of the appearance of height-- frequency characteristics with an even number of branches was offered by Ya. L. Al'pert [7]. He supposed that the characteristic with three components is a degenerated case of a quadruplet. However, in this case, triplets with an asymmetrical distribution of the branches would have to be observed more frequently (see Figure 3). In the meantime an analysis of the experimental material of the NIIZM ionosphere station showed that the symmetrical triple characteristics with a distance between the branches $f_1 - f_2 = f_2 - f_3 \approx \frac{FH}{2}$, where f_H is the gyromagnetic frequency (Figure 4), are encountered oftener than the asymmetrical ones.

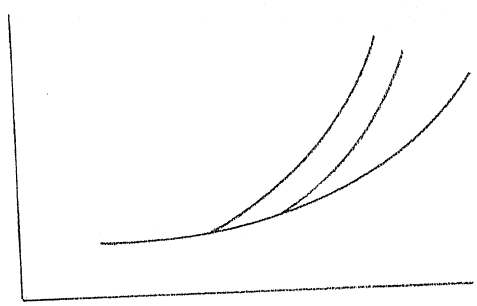

Figure 3

Triplets with an asymmetrical distribution of branches. (1) Uncommon wave. (2) Common wave. (3) z -- component (common wave).

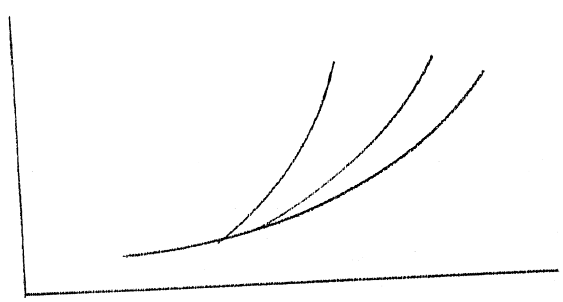

Figure 4

Triplet with a symmetrical distribution of branches. (Specifications same as in Figure 3).

A comparison with observations made at earlier and later hours shows that in the case of a symmetrical characteristic, branches 1 and 2 of the characteristic always remain, while branch 3 disappears. According to recently published observation material of the ionosphere station in Tiksi Bay [6], the triplets which come during reflection from E_{spor} always have a symmetrical disposition of branches.

In 1939, V. N. Kessenikh [8] expressed a supposition ac- cording to which the triple splitting may be explained by a second- ary splitting of the common ray in the region of the full internal reflection u = 1. This splitting would be into two components one of which is reflected with u+1 and the other with u+1 + w.

In fact, above the limit where u = 1, there may exist a wave with a left polarization, i.e., with a polarization of the same type as observed in the common wave. With u = 1, the refrac- tion exponent of the common wave becomes equal to zero, but, as Boze proved [9], in a non-homogeneous, anisotropic medium, the condi- tion of a full internal reflection is not equivalent to the zero value of the refraction exponent. A full internal reflection from the demarcation line between two media happens when the current flow across this line is equal to zero. In an isotropic medium this condition corresponds to the zero value of the refraction expon- ent. Under certain conditions in the anisotropic medium the en- ergy flow over the plane where the refraction exponent is equal to zero, may be different from zero.

Applying the general theory of propagation in a non-homo- geneous anisotropic medium to the ionosphere, Boze comes to the conclusion that during the propagation of electromagnetic waves in the ionosphere under 0° and 90° angles to the earth magnetic field, the condition of full internal reflection is equivalent to $n^2 = 0$. If, on the other hand, the propagation direction forms an acute angle with the direction of the tension vector of the earth magnetic field, then the refraction exponent being equal to zero is still not a condition for full internal reflection.

In order to study the possibility of appearance of an electromagnetic wave in the region above the critical plane where $u = 1$, we examined a model of an anisotropic medium with two layers [10].

We chose the values of u so that in the first layer the phase speed of the common wave is real and that of the uncommon wave is imaginary:

$$1 - w < u^{I} < 1.$$

In the second layer the phase speed of the uncommon wave is real, while that of the common wave is imaginary: $1 < u^{II} < 1 + w$. The common wave $(E ; E (x,y,) e^{-iknz}$ falls on the dividing line between layers I and II, perpendicularly to that dividing line. The border conditions must be fulfilled on the dividing line between the layers I and II: $E^{I} = E^{II}$, and $H^{I} = H^{II}$. In solving the border problem we find that the tension of the electric and the magnetic fields of the uncommon wave in the layer II differs from zero.

The value of the energy flow which has passed from layer I to layer II, depends upon the size of the angle Θ.

With small angles between the propagation direction and the tension vector of the earth magnetic field, practically all the energy passes through the plane where $u = 1$ and is reflected when $u = 1 + w$. With Θ equalling 5 degrees, $u^{I} = 0.99$, $u^{II} = 1.01$, $S_{pass} = 0.854 S_{desc}$. Therefore, a triple splitting may not occur during a propagation under a small angle to the tension vector of the earth magnetic field which is limited to a longitudinal propagation. This is because the uncommon component will then carry only a very small part of the general energy sent into the ionosphere and in practice only two reflections must be observed corresponding to $u = 1 - w$ and $u = 1 + w$.

When the angle Θ increases, the energy current which is carried by the common wave will increase rapidly. With $\Theta = 20^{\circ}$, $S_{pass} = 0.133 S_{desc}$, and $S_{reflect} = 0.867 S_{desc}$.

One may calculate the energy flow in an electomagnetic wave reflected from a plane where $u = 1 + w$ (z--component). This may be done on the same model by examining the inverse poblem.

Let us assume now that an electromagnetic wave ($E = E_{(x,y)}\, e^{iknz}$) descends from layer II into layer I. A partial reflection of the descending wave must occur on the dividing line.

The energy flow passing from layer II back into layer I, $S_{z\ reflect} = 0.0225_{desc}$ for an angle $\Theta = 20$ degrees, for $\Theta = 20^{\circ}$ the energy flow in the wave which is reflected with $u = 1 + w$ is only 2 percent of the flow of descending energy. Besides, the third component travels a longer way in the ionosphere. This probably explains the fact that the height--frequency characteristics with three components are seldom observed in the middle geomagnetic latitudes and only during the winter months and at night when absorbtion is low.

Most often the triple splitting must be observed in those regions of the globe where the propagation direction forms an angle of 8 -- 10 degrees with the direction of the tension vector of the earth magnetic field because that is when the energy flow in the common wave and in that wave which is reflected from the plane where $u = 1 + w$, is approximately equal. Because of its type, the z component must probably correspond to the common wave, because below the plane where $u = 1$ the phase speed of the uncommon wave is imaginary and the energy passing through the plane where $u = 1$ may be propagated only as a common wave. The experimental observations of the FIAN, which allow us to make a spacial division of common and uncommon reflected signals [11], testify to the fact that the z--component has a polarization corresponding to a common ray.

In closing we must note that the calculations and discussions mentioned refer to the case of high gradients of electron concentration in the ionosphere. As V. L. Ginsburg proved, [12], with a drop in the gradient of electron concentration, the angle θ, with which a triple splitting is possible, decreases.

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